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NANTUCKET, A MORAINAL ISLAND

A GEOLOGICAL MODEL OF NANTUCKET

THIS model (made at Harvard University), size 18 by 24 inches, scale 1:62500, or about an inch to the mile, is based on the United States Geological Survey topographic map of 1887, and on information from the latest geological surveys of the island. It was with the aim of producing an instructive relief of this portion of the deposits of the great continental ice sheet which here forms a type example of a morainal island, that this model was undertaken.

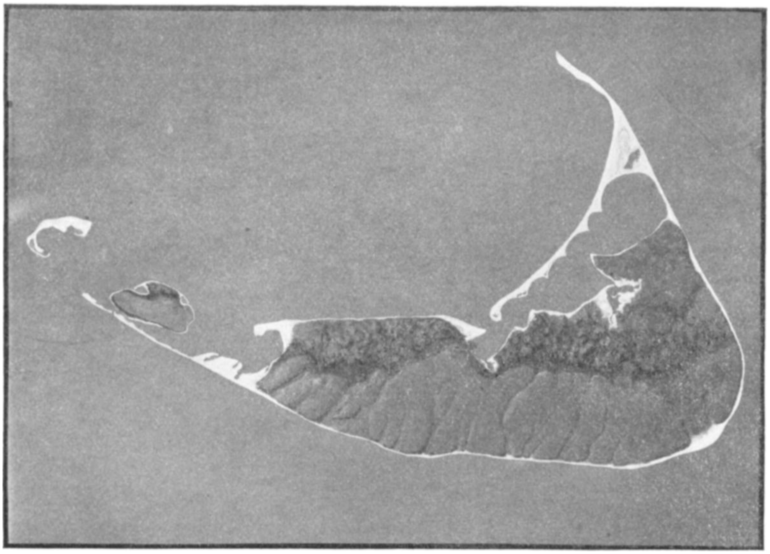

FIG. 1.—A Geological Model of Nantucket.

The principal topographic features,[1] shown by a profile sec-

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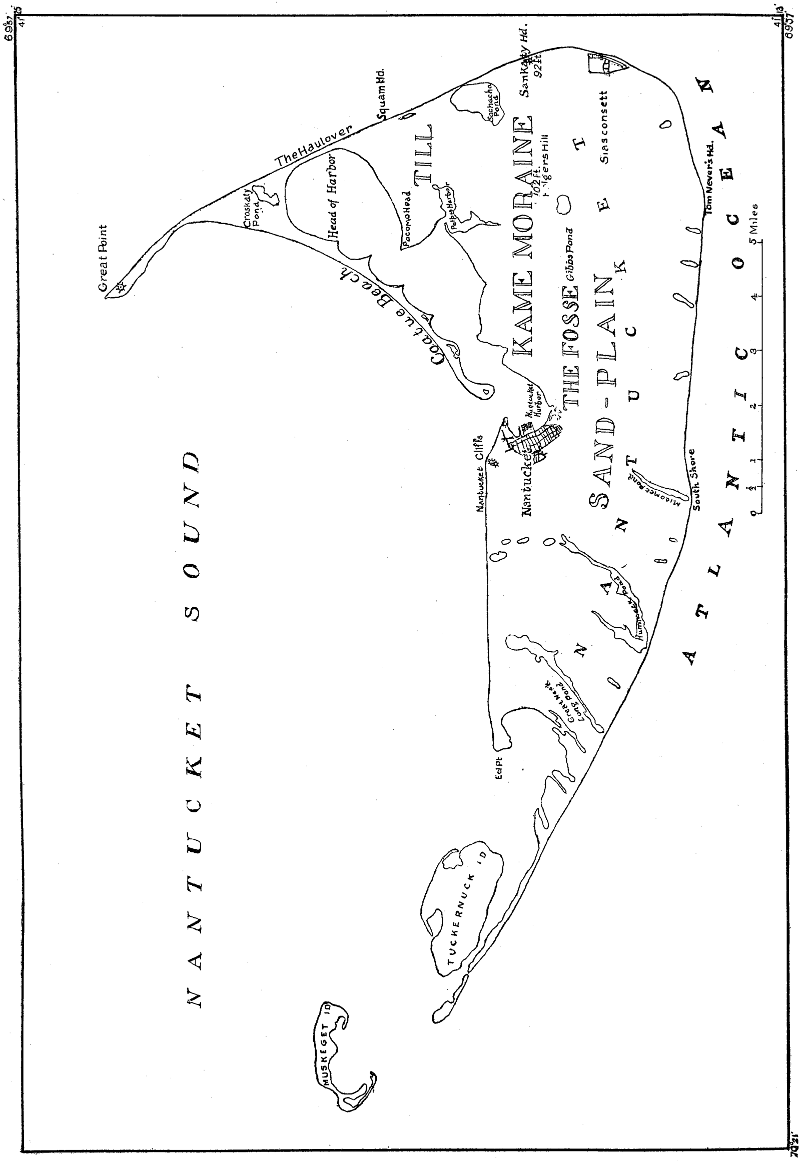
[1] After report on "The Geology of Nantucket," by PROFESSOR SHALER, U. S. Geol. Surv., Bull. 53, 1889; surveys by J. B. WOODWORTH, U. S. Coast Survey, *et. al.*



OUTLINE MAP OF NANTUCKET.

tion across the island (Fig. 2) may be briefly described under the following divisions.

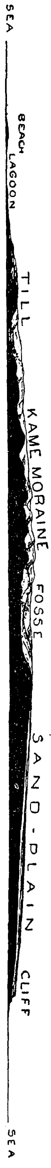


FIG. 2.—Profile Section across Nantucket Island.

1. *The ground moraine:* an area of irregularly distributed detritus, the undifferentiated till which lies on the northeast part of the island in the vicinity of Pocomo Head. (See map, Plate I.)

2. *The kame moraine:* a belt or ridge of kame-like mounds and kettles from 20 to 100 feet in altitude, which, running through the middle of the island, seems to form its back bone. On its south side, the kame moraine, descending to the 40-foot level, grades suddenly into a smooth-bottomed trough, which reaches the breadth of over one half a mile in its widest part. The southern side of this depression ascends 40 feet by an abrupt slope into the head of the sand plain. This ditch-like conformation lying between the kame moraine on the north and the sand plain on the south, runs throughout the extent of Nantucket, and Tuckernuck, and has been termed:

3. *The fosse.*—It is supposed that this depression marks the resting place of the ice, while the steep slope rising to the head of the sand plain marks the position of the ice front during the building of the frontal plain, This escarpment at the head of the sand plain has been called *the ice-contact slope.*

4. *The glacial sand plain:* which, falling gently from the terrace at its head to the sea on the south, represents the sand and gravel deposited from the streams as they flowed from the glacier front. The plain has a relatively smooth surface, sloping in its two miles of extent, from the 60-foot level to the cliff where the sea has cut the 20-foot level. At rather regular intervals of a quarter of a mile, the plain is interrupted by shallow troughs. These grade very gently into the head of the sand plain, and continue southward until truncated in their deepest expression by the seashore. These creases are today

practically dry, and represent the old drainage channels of glacial time. Some of them can be traced, not only toward the head of the sand plain, but extend quite through the kame moraine to the harbor on the north.

5. *Ponds or lakelets.*—There are several types of ponds on Nantucket. The most prominent lie in the lower ends of the long narrow drainage channels across which the along shore action has built barrier beaches. Hummock Pond, Long Pond, Micomet Pond, etc., are the largest of these basins. Sachacha and Gibbs Pond, by their circular forms alone would seem to be of different origin. Gibbs Pond lies in a depression of the fosse, Sachacha in a depression in the kame moraine across which a barrier beach has been thrown. Croskaty Pond is simply the unfilled enclosure between the trailing spits of Coatue Beach and Great Point. On the inner side of Coatue Beach, lagoon-like ponds have been formed behind the successive growths of sharp cusps. "Three of the cusps on the inside of the Coatue Spit, have no lagoons, but as the other two have, and since they are nearer the end of the spit and hence probably later formed, it is quite likely that the earlier formed forelands also began with lagoons."[1]

Professor Shaler has ascribed these Coatue cusps to tidal whirlpools. He says: "From a superficial inspection it appears that the tidal waters are thrown into a series of whirlpools, which excavate the shores between these salients and accumulate the sand on the spits."[2]

6. *Marshes and swamps* are plentiful and of origin similar to the ponds, the swamps as a rule being but the more advanced stage of pond-filling.

7. *Shoreline topography* is well exemplified. Nantucket's south side shows a coast well straightened by the dominating currents; the irregularities have been smoothed by beaching across the inlets and nipping the sand plain. A large part of the eroded material has gone to build up both the long spit extending toward Tuckernuck, and the rounded cusp or "apron"

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[1] F. P. GULLIVER: Proc. Am. Acad. Arts and Sci., Vol. XXXIV, 1899, p. 219.

[2] Bull. U. S. Geol. Surv., No. 53, 1889, p. 13.

which lies between Tom Never's and Sankaty Heads. Greta Point is made from the waste of the cliffs on the eastern side. Coatue Beach represents the tendency of the waves to straighten the north shore.

These shore forms are changing rapidly. The spit, formerly lying in front of Tuckernuck, for example, has been driven back and the island cliffed, sending out two wing bars, the western reaching a little beyond Muskeget.[1] At "South Shore" the foreland has been aggrading, while the blunted cusp near Tom Never's Head has worn nearly away.

Ten years ago Professor Shaler wrote:[2] "About one third of the coast line of Nantucket appears now to be undergoing erosion. At the eastern extremity of the island the erosive action appears at present to be limited to the section from the southern end of the Sankaty bluffs to a point just beyond Haulover Beach at the head of Coatue Bay. In 1873 Professor Henry L. Whiting found by a resurvey of this portion of the shore that the eastern or sea side of the coast at the Haulover had receded by an average of about one hundred feet since 1846. Between Sachacha Pond and the Haulover, especially at Squam Head, the wasting is evidently at this day quite rapid, probably amounting to at least a foot a year. The southern coast westward from Tom Never's Head, especially the section west of Weedweeder Shoal, is also the seat of considerable, though apparently inconstant, wear. A remarkable but probably temporary change has recently taken place in the long spit which forms the western extremity of the island as it is delineated on the Coast Survey maps. Twenty years ago this spit at low tide constituted an almost complete bridge extending from Nantucket to Tuckernuck Island. Of recent years this point has in good part been washed away almost down to its base near Further Creek. It seems possible that the existing separation of Tuckernuck from Nantucket may have been brought about by the action of marine currents within a relatively short time."

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[1] U. S. Coast and Geod. Surv. chart, No. 7, 1898.

[2] *Op. cit.*, p. 51.

The following table gives the geological horizons recognized at Nantucket and the corresponding topographic features which are represented in the legend of the model by separate colors.

Postglacial	Recent	Swamps and Marshes	
		Ponds — four types	
		Shoreline; beaches, spits, bars, cusps, cliffs	
Pleistocene	Last Glacial Epoch	Ground Moraine	
		Kame Moraine	Terminal Moraine
		Fosse	
		Frontal Sand Plain	
	Older Pleistocene	Sankaty Beds, shell deposits	
Cretaceous		Clays — artificially exposed (not indicated)	

I am indebted to Professors Shaler and Davis, and Mr. M. S. Jefferson, for helpful criticism on this model, and especially to Mr. J. B. Woodworth, whose valuable aid has much increased its merits.

G. C. Curtis.

A SKETCH OF THE GEOLOGY[1]

The island of Nantucket, which has been made the subject of a model by Mr. Curtis, is one of the most instructive portions of the terminal moraine of the last ice epoch in North America, because it is the most distinct and isolated of these glacial accumulations. Set in the waters of the ocean far to the south of the morainal belt of Cape Cod, and distant nearly its own length from the neighboring island of Martha's Vineyard, the peculiari-

[1] Written by J. B. Woodworth at the request of Mr. G. C. Curtis.

ties of its glacial form, despite the low relief of the island, are readily discerned.

This island, more than any other one of the New England islands,[1] approaches closely the purely morainic type. On Martha's Vineyard, Block Island, and Long Island, the relief is so far influenced by the topography of folded and eroded beds older than the moraine, that the true morainic expression is not fairly seen. It is in the nature of glacial drift to mask to a large extent the older rocks on which it lies. The drift of Nantucket affords no exception to this statement. Beneath this mantle of till, gravel, and sand, whose relief is shown in the model, there is a basement of pre-Pleistocene clays and older Pleistocene beds, which are exhibited in the sea cliffs on the east coast, and again on the north shore. These pre-morainal beds give rise to certain peculiarities in the topography, forms which even the morainal deposits do not entirely conceal. Remove both the moraine and the plain of gravel and sand on the south side of the island, and these older deposits would still stand above the present sea level as a number of small islands, one at Sankaty Head, one at Squam Head, and a larger islet about the size of Tuckernuck, extending westward from the site of the town of Nantucket. Other small islets might remain where the later drift now covers these older rocks.

The oldest known formation on the island is a bluish clay, probably of Cretaceous age. This clay makes up the ridge south and west of the town of Nantucket. The beds of this series are highly folded, as are also the strata of the same, and even more recent, date in the islands westward to Staten Island. Beneath these beds at an unknown but probably not great depth we should expect to find the extension of the granites and gneisses of southeastern Massachusetts.

Newer than this oldest clay formation is a series of sands and sandy clays containing a Pleistocene marine fauna, that of the well-known Sankaty Head beds. That these beds are older than the moraine is shown by the tilting and dislocation of the strata under the Sankaty Head lighthouse, their truncation by erosion and the unconformable deposition on them of the moraine, a relation first described by Upham, who showed that the beds do not belong to the so-called Champlain epoch as Dana was first led to suppose. Northward, at Squam Head, similar beds occur at high angles with folded clays, indicating that a profound disturbance of the strata over the site of the island took place sometime after the deposition of the older Pleistocene. Opinion is not unanimous concerning the cause of this and the similar dislocations which affect the islands of this group. According to one view, the dislocations originated in movements taking place in the earth's crust beneath, being simply a more pronounced phase of the disturbance which marks the "fall line" from New York southward at the inner edge of the coastal plain. Another view supposes the strata to have been disturbed by the mechanical action of an ice sheet advancing upon the soft strata of the Atlantic coastal plain. Since the action took place long before the deposition of the moraine which constitutes the chief feature of the island, the question need not be debated in a paper dealing primarily with the interpretation of a model of these more recent features.

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[1] A name proposed for the islands from Nantucket westward off the southern coast of New England, having a common geologic and geographic development.

The superficial formations of glacial origin on Nantucket appear in three very distinct belts extending east and west across the island and appearing on the dependent island of Tuckernuck. The small, wave-washed isle of Muskeget is probably a modified remnant of one of these belts. These deposits reappear on the easternmost part of Chappaquiddick. These bands may be spoken of as the kame moraine, the fosse, and the frontal plain. North of the hummocky ground, known as the kame moraine, in the eastern part of the island, is a small area of till-covered land. It seems to be the unstratified débris left upon the surface when the ice-sheet melted away, and may be dismissed with this explanation. Everywhere bordering the island is a fringe of recent marine deposits, in the making of which the original outline of the island has been much altered.

The significant features in the glacial formations are assembled in the accompanying diagrammatic cross section.

It is most convenient to consider the frontal plain first in describing the above named features of the island. This plain begins rather abruptly on the north as a terrace overlooking a more or less depressed region. The height of the plain along this summit line is, where greatest, about 60 feet above the sea level. The slope of the terrace to the fosse on the north is well marked, but not so steep as that of the typical moraine terrace of Gilbert,[1] or so sharply cuspate as the ice-ward edges of the sand plains described by Davis[2]. Yet this slope taken in connection with the fact that the plain inclines southward with well defined drainage creases, and that the materials are coarse at the crest line and grade into finer gravels and sands southward, affords good evidence that the plain was built against the front of the ice-sheet by excurrent streams. Viewed in this light, the terraced head of the plain indicates the east and west line along which the ice front stood in its southernmost extension.

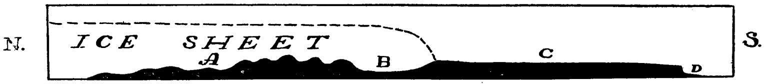

Fig. 4.—Cross section (diagrammatic) of the Island of Nantucket, showing the relation of the kame moraine (*A*), the fosse (*B*), and the frontal plain (*C*). *D* is the present beach. The dotted line represents the supposed profile of the ice sheet when the frontal plain was building.

This ice-contact slope is most distinct in the eastern part of the island, where it turns to the southeastward, as if the ice sheet extended seaward in this direction, covering at least the area now forming the Nantucket shoals. In the vicinity of the town of Nantucket, the hillock of pre-Pleistocene clays already mentioned has given rise to the type of sand plain which is dominant on Martha's Vineyard, one in which for the greater part of that island, the top of the sand plain was not built up to the base of the ice front where that rested on elevated ground. On the western part of the island and again on Tuckernuck, the ice-contact slope can be distinguished, affording a base line of reference from which to work out the relations of the glacial deposits to the ice sheet.

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[1] Lake Bonneville Monograph 1, U. S. Geol. Surv., 1890, pp. 81–83.

[2] Bull. Geol. Soc. Am. Vol. I, 1890, p. 195.

Accepting the slope at the head of the plain as denoting the position of the ice front, it follows that the fosse and the kame moraine are features originating in the area occupied by the ice. The fosse is simply the unfilled ground between the head of the plain and the belt of accumulations known as the kame moraine.

The kame moraine is supposed to be contemporaneous with the sand plain; one was building up by the action of excurrent streams outside of the ice while the other was accumulating inside the ice by the combined action of ice and water. This idea that the kame moraine is not frontal but submarginal in relation to the ice sheet by which it was built, first suggested, it is believed, by Salisbury for certain portions of the terminal moraine westward on the mainland, is consistent with the interpretation which has been placed on the origin of the kames near the heads of sand plains. Both ice-laid and water-laid drift tend to accumulate in the form of knobs and basins in this situation. At present, the explanation of the phenomenon can hardly be said to rank as an hypothesis, much less as "demonstrable theory."

One supposition is that the kame moraine marks the site of an earlier frontal deposit, *e.g.*, a sand plain, subsequently overridden by the ice sheet in its advance to the line marked by the head of the frontal plain. Stratified beds of sand and gravel seen under a coating of till in patches of kame moraine, as at Bridgewater, Mass., and the sandy clays under the till of the Nantucket kame moraine, show the possibility of the extra-glacial origin of the original deposit. But this explanation does not account for the seeming regularity in the occurrence of the belt of kame moraine at a distance of from half a mile to a mile back of the head of the outwash plain.

A second supposition makes the kame moraine built up under the lip of the ice sheet in the manner in which débris was seen accumulating in that situation by Chamberlin in the Greenland glaciers. Applying the observations made by Chamberlin upon the shearing of the upper ice over the lower and the involution of drift which thus comes about, to the case of the Nantucket type of terminal moraine, we may fairly suppose that when the moving ice sheet became blocked against the head of its growing sand plain, the upper ice began to shear over the lower, blocked prism of ice lying behind the sand plain. This shearing movement affected the lower part of the ice sheet for a long distance back from the actual front. At a distance of from one to two miles back from the front the bottom ice began to glide over the prism of dead ice lying back of the sand plain. (See Fig. 5.) As a result of this action the subglacial till dragged along on the bottom northward of this belt was gathered in the shear zone with moving ice above and dead ice below. Most of the till accumulated within a belt about a mile wide, leaving a strip in the case of Nantucket from a mile to half a mile wide between this accumulation and the head of the sand plain in which the débris was small in amount as compared with that deposited in the sand plain on one side and in the moraine on the other. On the melting out of the ice sheet, this outer part of the stagnant prism of ice, which was relatively free from drift, would give rise to the depression which separates the sand plain from the moraine. The melting out of the inner thin portion of the wedge of dead ice with its charge of till would result in the hummocky topography which gives the moraine the striking resemblance to a belt of kames. In the case of the water-worn gravels and sands which accumulate in this belt, it is to be supposed that in the shearing movement of the upper ice over the

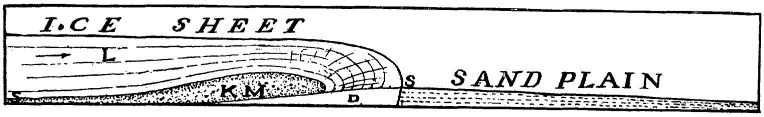

FIG. 5.—Diagram showing supposed mode of accumulation of Kame moraine. *D*, Prism of dead ice blocked by sand plain barrier. *L*, Live ice dragging up drift into K M, the position of the Kame moraine. *S S*, Principal plain of shearing.

lower stagnant prism of ice, the subglacial drainage is interrupted and the detritus is involved in the movements of the ice as in the case of the till. It is favorable to this view that, in cases where such action may be invoked, eskers are absent, and the sand plain appears to have been fed by streams flowing off the ice sheet.

Certain ponds and furrows which lie in the kame moraine belt show that the drainage of the ice sheet, perhaps a late phase of the system, coursed through the field quite independently of the motion of the ice, which may well have been stagnant at the time. On the east, the furrow connecting Polpis harbor with the drainage crease in the sand plain has been noted by Shaler, as an indication of the movement of subglacial water as in a pipe to the front. On the other hand, creases west of the town connecting with deep, pothole-like ponds in the moraine belt suggest the holes at the bottom of falls of water off the edge of the ice sheet rather than depressions due to the melting out of blocks of ice.

The question of sea level in relation to the sand plain at the time it was building is a debatable one. The absence of anything like wave action on the island above the present sea level is presumptive evidence that the sea has not stood higher than it now does upon this coast since the glacial formations were deposited. A comparison of the Nantucket plains with the deltas of glacial rivers such as those of the Malaspina district in Alaska and of Heard Island in the Indian ocean would lead us to regard the sand plain as made in the open air.

The student who is desirous of studying many interesting details concerning the geology and physical geography of this island should supplement this brief account of some of its features and the questions which they raise, by reading Professor Shaler's report on its geology.[1]

J. B. WOODWORTH.

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[1] The Geology of Nantucket. Bulletin No. 53, 1889, U. S. Geol. Surv., pp. 55. 10 plates. By N. S. SHALER. This work gives references to numerous other papers concerning the paleontology and moraines of the island.